Data–Driven Smart Sustainable Urbanism:
The Intertwined Societal Factors Underlying its Materialization, Success, Expansion, and Evolution

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Abstract

Visions of future advances in science and technology (S&T) inevitably bring with them wide–ranging common visions on how societies, and thus cities as social organizations, will evolve in the future and the immense opportunities this future will bring. This relates to the role of science–based technology in modern society. The focus here is on big data science and analytics and the underpinning technologies as an instance of S&T and its role in advancing sustainability in modern cities. This relates to what has been dubbed data–driven smart sustainable urbanism. However, there is a little understanding about how it has emerged and why it has become institutionalized and interwoven with politics and policy—urban dissemination. Therefore, this paper examines the intertwined societal factors underlying its materialization, success, expansion, and evolution, as well as critically discusses urban science and big data technology as social constructions in terms of their inherent flaws, limits, and biases. This paper argues that data–driven smart sustainable urbanism is shaped by socio–cultural and politico–institutional structures. And it will prevail for many years to come given the underlying transformational power of big data science and analytics, coupled with its legitimation capacity associated with the scientific discourse as the ultimate form of rational thought and the basis for legitimacy in knowledge–making and policy–making. This paper also argues that there is a need for re–casting urban science in ways that reconfigure the underlying epistemology to recognize the complex and dynamic nature of smart sustainable cities, as well as for re–casting them in ways that re-orientate in how they are conceived.

Keywords: Data–driven smart sustainable urbanism, smart sustainable cities, big data computing, datafication, urban science, data science, sustainability, sustainable development, technology

1. Introduction

There is an increasing recognition that emerging and future ICT constitute a promising response to the challenges of sustainable development in the face of urbanization due to its tremendous, yet untapped, potential for solving many socio–economic and environmental problems (see, e.g., Angelidou et al. 2017; Batty et al. 2012; Bibri and Krogstie 2017a; Kramers et al. 2014). Therefore, advanced ICT has recently come to the fore and become of fundamental importance as to mitigating the negative effects of urbanization and tackling the conundrums of sustainability. Many urban development approaches emphasize the value and role of big data technologies and their novel applications as an advanced form of ICT in advancing sustainability (e.g., Angelidou et al. 2017; Al Nuaimi et al. 2015; Batty et al. 2012; Bettencourt 2014; Bibri 2018a, b, 2019a, b; Pantelis and Aija 2013; Taghavi et al. 2014; Twonsend 2013).

Against the backdrop of the unprecedented rate of urbanization and the mounting challenges of sustainability, an array of alternative ways of understanding, planning, designing, operating, managing, and governing cities based on advanced ICT is materializing and rapidly evolving, providing the raw material for how smart cities can transition towards the needed sustainable development and sustainable cities can enhance their sustainability performance. These two main urbanism approaches: sustainable cities and smart cities, as a set of interrelated practices have been developing for quite some time: since the diffusion of sustainable development around the early 1990s and the prevalence of ICT around the mid 1990s, respectively. But what is presently new is that the emerging urban initiatives and endeavors are rather shifting from merely focusing on the application of sustainability knowledge to urban practices or the development and deployment of smart technologies to optimize these practices to connecting the sustainable city and the smart city as both landscapes and approaches (Bibri 2019a, b). Worth pointing out is that there are several differences between sustainable smart cities and smart sustainable cities. One obvious distinction is that the former involve those cities that badge themselves as smart (e.g., Barcelona, Singapore, etc.) and are striving to become sustainable. And this class of cities often relates to technologically advanced nations. The latter involve those cities that badge themselves as sustainable (e.g., Stockholm, Malmö, etc.) and are striving to improve, advance, and maintain their contribution to sustainability using the advanced forms of ICT. And this class of cities pertains to ecologically and technologically advanced nations. However, much of what can be said on sustainable smart cities does apply to smart sustainable cities due to the relatively parallel emergence of these two urbanism approaches and the many overlapping technical aspects between them, coupled with their prominence and significance as research areas today (see Bibri 2019a for a detailed review).

In parallel, there has recently been a conscious push for cities across the globe to be smarter and more sustainable by developing and implementing big data technologies and their novel applications across various urban domains to enhance and optimize their operations, functions, services, designs, strategies, and policies. Underneath this advanced form of ICT solutions, there indeed is a vast deluge of big data that is being harnessed, analyzed, and put to work for the benefit and health of cities in terms of sustainability, efficiency, resilience, and the quality of life. As a research wave and direction, big data computing has recently attracted urban scholars and scientists from diverse disciplines as well as urban practitioners from different professional fields due to its significant contribution to urbanism with respect to various urban domains such as transport, mobility, economic forecasting, equity, built environment, and so on (e.g., Batty 2013; Batty et al. 2012; Bibri 2018b, 2019b, d; Bibri and Krogstie 2017a, 2019a, b; Bettencourt 2014; Kitchin 2014a, 2016a). Big data computing is increasingly seen to provide unsurpassed and innovative ways to address the rising environmental and rising socio–economic concerns facing contemporary cities through enhancing, optimizing, and advancing urban operational functioning, planning, design, development, and governance in line with the vision of sustainability. Hence, urban planners, strategists, and policymakers are faced with unique opportunities in this direction.

Visions of future advances in science and technology (S&T), predominately computing and ICT, inevitably bring with them wide–ranging common visions on how societies, and thus cities as social organizations, will evolve in the future as well as the immense opportunities this future will bring (Bibri and Krogstie 2016). This relates to the role of science–based technology in modern society in terms of its development, a half–a–century debate (e.g., Biagioli 1999; Jasanoff et al. 1995; Sismondo 2003; Hess 1997) within which the assumptions and claims made in the preceding discussion are positioned. The focus here is on the role of big data science and analytics and the underpinning technologies in advancing sustainability in modern cities. This form of S&T has recently permeated contemporary urban debates, policy, and politics in the sphere of smart sustainable/sustainable smart urbanism. It has also been challenged and questioned by some scholars, often exposing the risks and drawbacks of the so–called techno–scientific achievements. However, as a new area of S&T, big data science and analytics embodies an unprecedentedly transformative power—which is manifested not only in the form of revolutionizing science and transforming knowledge, but also in advancing social practices, catalyzing major shifts, and fostering societal transitions (Bibri 2019c). Of particular relevance, it is instigating a massive change in the way both smart cities and sustainable cities are understood, studied, planned, designed, operated, and managed so as to improve, advance, and maintain their contribution to the goals of sustainable development in the face of the expanding urbanization (Bibri 2019a, b, c, d; Kitchin 2014a, b, 2015a, 2016a). This relates to what has been dubbed data–driven smart sustainable/sustainable smart urbanism; a new era which is presently unfolding wherein smart sustainable/sustainable smart urban practices and processes are becoming highly responsive to a form of data–driven urbanism (Bibri 2019b). ‘At the heart of data–driven urbanism is a computational understanding of city systems that reduces urban life to logic and calculative rules and procedures, which is underpinned by a…realist epistemology. This epistemology is informed by and sustains urban science…, which seek to make cities more knowable and controllable' (Kitchin 2016a, p. 2). However, there is a little understanding about how it has emerged and why it has become institutionalized and interwoven with politics and policy—urban dissemination.

Against the preceding background, this paper examines the intertwined societal factors underlying its materialization, success, expansion, and evolution, as well as critically discusses urban science and big data technology as social constructions in terms of their inherent flaws, limits, and biases. This paper argues that data–driven smart sustainable urbanism is shaped by socio–cultural and politico–institutional structures. And it will prevail for many years to come given the underlying transformational power of big data science and analytics, coupled with its legitimation capacity associated with the scientific discourse as the ultimate form of rational thought and the basis for legitimacy in knowledge–making and policy–making. This paper also argues that there is a need for re–casting urban science in ways that reconfigure the underlying epistemology to recognize the complex and dynamic nature of smart sustainable cities, as well as for re–casting them in ways that re-orientate in how they are conceived.

This paper unfolds as follows. Section 2 introduces and describes the relevant theoretical and disciplinary foundations, with an emphasis on cross–disciplinary issues. Section 3 provides a review of related works. Section 4 delves into the main contribution of the paper. Section 5 provides a critical account of urban science and big data technology as social constructions. This paper ends, in Section 6, with concluding remarks along with discussion and reflection.

2. Theoretical and Disciplinary Foundations

2.1. Smart Sustainable Urbanism: Planning, Design, and Development

As a research field and practice, urbanism covers the study of urban phenomena in terms of the urbanization and organization of cities, as well as the practice of urban planning and development. Rooted in the study of sustainability and urban planning and design in a rapidly urbanizing world, sustainable urbanism is concerned with the study of cities and the practices to plan. develop, and design them that focus on reducing material use, lowering energy consumption, mitigating pollution, and minimizing waste, as well as improving social equity and the quality of life (Bibri 2019b)

The evolving research and practice in the field of smart sustainable/sustainable smart urbanism tends to focus on exploiting, analysing, and harnessing the ever–increasing deluge of data flooding from urban systems and domains, and leveraging the outcome in the transition to, and advancement of, sustainable development. Urban systems include built form, urban infrastructure, ecosystem services, human services, and administration and governance, and urban domains involve transport, traffic, mobility, energy, natural environment, land use, healthcare, education, science and innovation, and public and social safety. Thus, urban systems and domains overlap in many aspects and are associated with the physical, environmental, social, and economic dimensions of sustainability. Further, smart sustainable/sustainable smart urbanism entails developing and applying new urban intelligence functions as an advanced form of decision support on the basis of the useful knowledge to be extracted from large masses of data by means of data analytics techniques. Urban intelligence functions represent new conceptions of how smart sustainable/sustainable smart cities function and utilize and combine complexity science and urban science in fashioning powerful forms of urban simulations models and optimization and prediction methods that can generate urban structures and forms that improve sustainability, efficiency, resilience, and the quality of life (Batty et al. 2012; Bibri 2019b, d). In a nutshell, the data–driven approach is of paramount importance to smart sustainable/sustainable smart urbanism. Indeed, in this field, the operation and organization of urban systems, domains, and networks and related processes require not only complex interdisciplinary and transdisciplinary knowledge, but also sophisticated technologies and powerful data analytics capabilities.

Urban planning is concerned with the development and design of land use and the built environment. It involves transportation planning, environmental planning, land–use planning, policy recommendations, and public administration, as well as strategic thinking, sustainable development, landscape architecture, civil engineering, and urban design (Bibri and Krogstie 2017a). Sustainable urban planning is the process of guiding and directing the development and design of land, urban environment, urban infrastructure, and related processes, activities, and services in ways that meet the required level of sustainability. As such, it involves defining the long–term goals of sustainability; formulating sustainable development objectives to achieve such goals; arranging the means and resources required for attaining such objectives; and implementing, monitoring, steering, evaluating, and improving all the necessary steps in their proper sequence towards reaching the overall aim. Its technical features entails the application of advanced ICT as a set of computational and scientific approaches and technical processes. Recent evidence (e.g., Angelidou et al. 2017; Batty et al. 2012; Bettencourt 2014; Bibri 2018a, b, 2019a, b, d; Bibri and Krogstie 2017b) lends itself to the argument that an integration of the defining elements of urban planning (i.e., natural ecosystems, physical structures, urban forms, spatial organizations, natural resources, urban infrastructures, socio–economic networks, and ecosystem and human services) with cutting–edge big data technologies can create more sustainable, resilient, equitable, safe, and livable cities.

Urban design is an integral part of urban planning. As an academic field, it is concerned with planning, landscape architecture, and civil engineering, as well as sustainable urbanism, ecological urbanism, sustainable design, ecological design, and strategic design (Bibri and Krogstie 2017a). Dealing with the design and management of the public domain and the way this domain is experienced and used by urbanites, urban design refers to the process of designing, shaping, arranging, and reorganizing urban physical structures and spatial patterns. As to its sustainable dimension, it is aimed at making urban living more environmentally sustainable and urban areas more attractive and functional (e.g., Aseem

2013; Boeing et al. 2014; Larice and MacDonald 2007). In this respect, urban design is about making connections between forms for human settlements and environmental and social sustainability, built environment and ecosystems, people and the natural environment, economic viability and well–being, and movement and urban form (Bibri 2018a). Furthermore, the link between the emerging urban intelligence functions being developed using advanced ICT and urban design principles and strategies lies in that the city structures, forms, and spatial organizations together with scale stabilisations are generated by powerful new forms of simulation models and optimization and prediction methods fashioned on the basis of complexity science and urban science (Bibri 2019b). The resulting outcome generated can improve sustainability, efficiency, equity, resilience, and the quality of life (Batty et al. 2012). Advanced simulations models and related methods hold great potential to inform future urban designs. They relate to the emerging approaches to urban design (and planning) driven by the increasing space–time convergence in modern cities (Batty et al. 2012).

The way cities are intelligently planned and designed is of paramount importance to strategic sustainable urban development. Urban development refers to urbanization with its different dimensions, especially physical (land use change), geographical (population), societal (social and cultural change), and economic (agglomeration). Urban planning as a technical and political process is seen as a valuable force to achieve sustainable development through design, among other things. Sustainable urban development can be viewed as an alternative approach to urban thinking and practice. It focuses primarily on addressing and overcoming the escalating environmental problems and the rising socio–economic issues associated with the predominant paradigm of urban development by mitigating or eliminating its negative impacts on the environment and improving human well–being. In short, sustainable urban development is a strategic approach to achieving the long–term goals of sustainability. As such, it requires that scholars, practitioners, organizations, institutions, and governments agree upon concrete ways to determine the most effective approaches and strategic actions in a concerted effort to reach a sustainable future. Furthermore, as the focus here is on smart sustainable/sustainable smart cities, achieving the goals of sustainability through sustainable development as a strategic approach entails unlocking the untapped potential and transformational power of advanced ICT in terms of its innovative solutions and sophisticated approaches pertaining to big data technologies and their applications due especially to its disruptive, substantive, and synergetic effects. The way forward is to direct the research and innovation agenda of advanced ICT with the agenda of sustainable development, thereby justifying the future investments in big data technology by the quest for overcoming physical infrastructure inefficiencies, environmental concerns, and socio–economic needs related to urban development as to urbanization and its dimensions, in addition to guiding and sustaining this momentum through effective policy frameworks and measures and relevant institutional structures and practices (Bibri 2018a). Especially, urban growth and ICT development is a form of symbiosis (Townsend 2013). This entails an interaction that is of advantage to, or a mutually beneficial relationship between, both ICT and urbanization. One way of looking at this form of tie–in is that urbanization can open entirely new windows of opportunity, or simply provide a fertile environment, for cities to act as vibrant hubs of technological innovations in a bid to solve a wide variety of environmental, social, and economic problems and challenges, thereby mitigating the potential negative effects of urbanization.

2.2. Data Science and Analytics

Data science is largely seen as the umbrella discipline that incorporates a number of other disciplines. As an interdisciplinary field, it employs theories, methodologies, and practices from across several fields within the context of statistics, mathematics, computer science, information science, software engineering, and data engineering while morphing them into a new discipline. It is often said to include particularly the allure of big data, the fascination of unstructured data, the advancement of data–intensive techniques and algorithms, and the precision of mathematics and statistics. The practical engineering goal of data science: actionable knowledge extracted from large bodies of data and consistent patterns for generating predictive models, takes it beyond traditional approaches to analytics.

Data science employs scientific methods, systems, processes, and algorithms to extract useful knowledge and valuable insights from data in various forms using a set of analytics techniques. Data science and analytics techniques, such as data mining and pattern recognition, statistical analysis, data visualization and visual analytics, and prediction and simulation modeling are largely in the early stages of their development given that the statistical methods that have prevailed over several decades were originally designed to perform data–scarce science, i.e., to identify significant correlations and relationships from small, clean sample data sizes with known attributes. Nonetheless, recent years have witnessed a remarkable progress with regard to handling big data and performing sophisticated analytics, and these have been utilized in urban science. The term 'big data' is essentially used to mean collections of datasets whose volume, velocity, variety, exhaustivity, relationality, and flexibility make it so difficult to manage, process, and analyze the data using the traditional database systems and software techniques. The term 'big data analytics' denotes 'any vast amount of data that has the potential to be collected, stored, retrieved, integrated, selected, preprocessed, transformed, analyzed, and interpreted for discovering new or extracting useful knowledge. Prior to this, the analytical outcome (the obtained results) can be evaluated and visualised in an understandable format before their deployment for decision–making purposes (e.g., improving, adjusting, or changing an operation, function, service, strategy, or policy)… In the domain of smart sustainable urbanism, big data analytics refers to a collection of sophisticated and dedicated software applications and database management systems run by machines with very high processing power, which can turn a large amount of urban data into useful knowledge for enhanced decision–making and deep insights in relation to various urban domains, such as transport, mobility, traffic, environment, energy, land use, waste management, education, healthcare, public safety, planning and design, and governance' (Bibri 2018b, p. 234).

2.3. Urban Science

Urban science is an interdisciplinary field within which data science is practiced to inform and sustain the core of data–driven urbanism using big data computing and the underpinning technologies. Its ultimate goal of urban science is to enhance decision–making pertaining to a large number and variety of domains across many fields through the practice of big data analytics. Positioned at the intersection of science and design, urban science draws on new disciplines in the natural science and information science, and seeks to exploit the development of modern computation and the growing abundance of data. As a research field, it is concerned with the study of diverse urban issues and problems, and thereby aims to produce both theoretical and practical knowledge that contributes to understanding and solving them in contemporary cities. In this respect, it entails making sense of cities as they are by identifying relationships and urban laws, as well as predicting and simulating likely future scenarios under different conditions, potentially providing valuable insights for planning and development decision–making and policy formulation (Kitchin 2015a). As such, it involves data–analytic thinking and computational modelling and simulation approaches to exploring, understanding, and explaining urban processes, and also addressing several challenges posed by urban data. The two fundamental ones are: (1) how to handle and make sense of billions of observations that are being generated on a dynamic basis (Batty et al. 2012) and (2) how to translate the insight derived into new urban theory (fundamental knowledge) and actionable outcomes (applied knowledge) (Batty 2013; Foth 2009; Ratti and Offenhuber 2014). In this respect, urban science radically extends quantitative forms of urban studies, blending in data science, social physics, and geocomputation (Batty 2013).

3. A Review of Related Works

Big data technologies have become essential to the functioning of both smart cities and sustainable cities. Consequently, their practices and processes are becoming highly responsive to a form of data-driven urbanism. In more detail, 'we are moving into an era where instrumentation, datafication, and computerization are routinely pervading the very fabric of cities, coupled with the…integration and coordination of their systems and domains. As a result, vast troves of data are generated, harnesses, analysed, and exploited to control, manage, organize, and regulate urban life… This data-driven approach to urbanism is increasingly becoming the mode of production for smart sustainable cities.' (Bibri 2019c, p. 1) In a nutshell, a new era is presently unfolding wherein both smart urbanism and sustainable urbanism are increasingly becoming data-driven.

In one of the earlier works on data–driven urbanism, Batty (2013) describes how the growth of big data is shifting the emphasis from longer term strategic planning to short–term thinking about how cities function and can be managed. His argument revolves around the sea change in the kinds of data that are emerging about what happens where and when in cities, and how it is drastically altering the way we conceive of, understand, and plan smart cities. Bettencourt (2014) explores how big data can be useful in urban planning by formalizing the planning process as a general computational problem. The focus in his paper is on scientific (complexity science) and engineering principles (big data technologies) pertaining to data–driven urbanism, and how they particularly relate to urban policy, management, and planning as to achieving new solutions to wicked and intractable urban problems. In his article 'The Real–time City? Big Data and Smart Urbanism' Kitchin (2014a) focuses on smart cities as increasingly composed of and monitored by pervasive and ubiquitous computing, and drawing on a number of examples, details how cities as being instrumented with digital devices and infrastructure produce big data which enable real–time analysis of city life, new modes of urban governance, and provide the raw material for envisioning and enacting more efficient, competitive, productive, open, and transparent cities. He moreover provides a critical reflection on the implications of big data and smart urbanism, examining five emerging concerns: the politics of big urban data; technocratic governance and city development; corporatization of city governance and technological lock–ins; buggy, brittle and hack–able cities; and the panoptic city. A large part of this examination is also the aim of Kitchin's (2015a) paper, which indeed provides a critical overview of data–driven, networked urbanism and smart cities focusing in particular on the relationship between data and the city (rather than network infrastructure or computational or urban issues), and critically examines a number of urban data issues, including corporatization, ownership, control, privacy and security, anticipatory governance, and technical challenges. Kitchin (2016) examines the forms, practices, and ethics of smart cities and urban science, paying particular attention to: instrumental rationality and realist epistemology; privacy, dataveillance and geosurveillance; and data uses, such as social sorting and anticipatory governance. Overall, the above works lack an important strand to the topic of smart or data–driven urbanism: sustainability, and also tend to focus on either technical or political issues related to urban big data. In view of that, Bibri (2019a) provides a comprehensive, state–of–the–art review and synthesis addressing the sustainability and unsustainability of smart urbanism and related big data applications in terms of research issues and debates, knowledge gaps, technological advancements, as well as challenges and common open issues.

Topical studies tend to deal largely with data–driven smart urbanism in terms of economic growth, governance, planning, as well as service provisioning (e.g., Batty 2013; Battu et al. 2012; Bibri 2019a; Bettencourt 2014; Hashem et al. 2016; Khanac, Pervaiz and Abbasi 2017; Kitchin 2014a, 2015a, b, 2016a, b; Kitchin et al. 2017; Rathore 2018) while barely exploring how this approach can improve sustainable urbanism and vice versa in terms of urban practices and processes and their synergistic effects with regard to boosting sustainability benefits—under what is labeled 'data–driven smart sustainable/sustainable smart urbanism' (Bibri 2019a, b). This paucity of research pertains particularly to the untapped potential of big data technologies and their novel applications for enhancing the environmental, economic, and social aspects of sustainability in the context of smart sustainable/sustainable smart cities (Bibri 2018a, 2019a). Especially, many of the emerging smart solutions are not aligned with the goals of sustainable development (Ahvenniemi et al. 2017), and this particularly relates to the deficiencies, limitations, and misunderstandings associated with smart cities (see Bibri 2019a for a detailed review). However, a recent research wave has started to focus on incorporating the goals of sustainable development into the concept and approach of smart cities in a bid to enhance their sustainability performance, as well as on smartening up sustainable cities in ways that can improve, advance, and maintain their contribution to the goals of sustainable development—mainly with support of big data technologies and their novel applications (e.g., Al Nuaimi et al. 2015; Batty et al. 2012; Bettencourt 2014; Bibri 2018b, 2019a, b, d; Bibri and Krogstie 2017b). This wave of research revolves particularly around amalgamating the landscapes of and the approaches to sustainable cities and smart cities in a variety of ways in the hopes of reaching the required and optimal level of sustainability, respectively, and enhancing the living standard of citizens. It is generally concerned with addressing a large number and variety of issues related to sustainable cities and smart cities. Therefore, numerous research opportunities are available and can be explored in the context of smart sustainable/sustainable smart cities. Especially, this integrated approach tends to take several forms in terms of combining the strengths of sustainable cities and smart cities based on how the idea of smart sustainable/sustainable city can be conceptualized and operationalized (see, e.g., Angelidou et al. 2017; Bibri 2018b; Bibri and Krogstie 2017b; Kramers et al. 2014; Rivera, Eriksson and Wangel 2015; Shahrokni et al. 2015; Yigitcanlar and Lee 2013). However, research on the uses of big data in relation to sustainable urban development tends to be scant (Bibri 2019a, b). This paucity of research can be explained by the fact that smart sustainable/sustainable smart cities are a new urban phenomenon and only became widespread during the mid 2010s (Bibri and Krogstie 2017a). As part of this paucity of research, there is a little understanding about how data–driven smart sustainable/sustainable smart urbanism has emerged and materialized, and why it has become institutionalized and interwoven with politics and policy—urban dissemination.

4. The Intertwined Societal Factors Behind Data–Driven Smart Sustainable Urbanism

4.1. Long–Lasting Trends

As with all paradigms of urbanism historically, data–driven smart sustainable/sustainable smart cities have emerged and materialized as a result of an amalgam of several dominating and long–lasting trends. Bibri (2019b) provides a detailed qualitative analysis of the key forms of trends shaping and driving the emergence and materialization of the phenomenon of smart sustainable/sustainable smart cities as a leading paradigm of urbanism. The key trends identified include the following:

- Global shifts: sustainability, ICT, and urbanization.
- Intellectual discourses: sustainable urbanism, smart urbanism, data–driven urbanism, and sustainable development.
- Academic discourses: sustainable cities, smart cities, and smart sustainable/sustainable smart cities.
- Computing paradigms: pervasive computing, ubiquitous computing, the IoT, and big data computing.
- Scientific paradigms: data–intensive science.
- Technological innovations: big data technologies, analytics, applications, and ecosystems.

These forms of trends reflect a congeries of global and societal forces behind the continuation of smart sustainable/ sustainable smart cities as a set of multiple approaches to, and pathways to achieving, sustainable urban development. For a detailed account and discussion of these trends and their integrative aspects, the interested reader can be directed to Bibri (2019b). However, the dynamic interplay between these varied forms of trends, which will undoubtedly continue to evolve simultaneously and affect one another in a mutual process for many years yet to come, is the backcloth against which many recent urban innovations and transitions have evolved, and thus numerous opportunities have been created and exploited, especially in the ambit of data–driven smart sustainable/sustainable smart urbanism. Indeed, these trends are not only shaping and driving the emergence and materialization of this paradigm, but also instigating a number of other related expected developments.

4.2. Expected Developments

Smart cities are increasingly connecting the ICT infrastructure, the physical infrastructure, the social infrastructure, and the economic infrastructure to leverage their collective intelligence, thereby striving to render themselves more sustainable, efficient, functional, resilient, livable, and equitable. It follows that smart cities of the future seek to solve a fundamental conundrum of cities—ensure sustainable socio–economic development, equity, and enhanced quality of life at the same time as reducing costs and increasing resource efficiency and environment and infrastructure resilience. This is increasingly enabled by utilizing a fast–flowing torrent of urban data and the rapidly evolving data analytics technologies; algorithmic planning and governance; and responsive, networked urban systems. In particular, the generation of colossal amounts of data and the development of sophisticated data analytics for understanding, monitoring, probing, planning, and regulating the city are a key significant aspect of smart cities that is being embraced by sustainable cities to improve, advance, and maintain their contribution to the goals of sustainable development (e.g., Bibri 2018b, 2019b; Bibri and Krogstie 2017b). For supra–national states, national governments, and city officials, smart cities offer the enticing potential of environmental and socio–economic development, and the renewal of urban centers as hubs of innovation and research (e.g., Batty et al. 2012; Bibri 2019a; Kitchin 2014; Kourtit et al. 2012; Townsend 2013). While there are several main characteristics of smart cities as evidenced by industry and government literature (e.g., Holland 2018; Kitchin 2014), the one that this paper is concerned with is environmental, economic, and social sustainability.

The interlinked development of sustainability, ICT, and urbanization has recently converged under what is labelled 'smart sustainable/sustainable smart cities'. The whole idea of this integrated and holistic approach to urbanism revolves around leveraging the convergence, ubiquity, and advance of ICT, especially big data computing and the underpinning technologies, in the transition towards the needed sustainable development in an increasingly urbanized world. Therefore, such approach to urbanism is increasingly gaining traction and prevalence worldwide as a response to the imminent challenges of sustainability and urbanization. In other words, both the ecologically and technologically advanced nations are exhibiting shifting patterns as to responding to the goals of sustainable development and to the global call for tackling the pressing issues of urbanization by developing and implementing the innovative solutions and sophisticated approaches being offered by big data technologies and their novel applications. A futures study being conducted by Bibri and Krogstie (2019a, b), whose aim is to analyze, investigate, and develop a novel model for smart sustainable city of the future, identifies, as part of the strategic problem orientation phase of the backcasting approach being applied to achieve this aim, several key expected developments related to data–driven smart sustainable urbanism. These are believed to be already happening or to arrive soon, and include, but are not limited to, the following:

- Sustainable cities are increasingly embracing big data technologies and their novel applications to improve, advance, and maintain their contribution to the goals of sustainable development towards achieving the optimal level of sustainability.
- Smart cities are increasingly incorporating the goals of sustainable development in their conceptualization and operationalization as part of new pathways towards enhancing their sustainability performance by relying heavily on big data computing and the underpinning technologies.
- Sustainable cities and smart cities are becoming more and more connected as approaches and less fragmented as landscapes.
- Instrumentation, computerization, and computation are routinely pervading the very fabric of sustainable cities and smart cities.
- Sustainable cities and smart cities are becoming increasingly datafied and thus dependent upon their data to operate properly—and even to function at all with regard to many domains of urban life.
- Sustainable urban and smart urban practices (operational functioning, planning, design, development, and governance) are becoming highly responsive to a form of data–driven urbanism.
- Data–driven urbanism is increasingly becoming the mode of production for smart sustainable/sustainable smart cities.
- Data–intensive science as a fourth scientific paradigm is drastically changing how urban scholarly and scientific research is done.

Some of the above listed expected development have already been discussed in the literature and in the first part of this subsection. Others are the object of Section 4.4. And the very last one is addressed next.

4.3. Scholarly and Scientific Shifts

In contrast with urban knowledge derived from longer standing, more traditional urban studies, data science as practiced within the field of urban science offers the potential for the kind of urban knowledge that is inherently longitudinal, and has greater breadth, depth, scale, and timeliness (Batty et al. 2012; Kitchin 2016a; Lazer 2009) in the context of smart sustainable/sustainable smart urbanism. This is being enabled and afforded by the unfolding and soaring deluge of urban big data. With respect to the data–driven urban knowledge, the emphasis has been on the development of new big data analytics that utilize sophisticated techniques and advanced mathematical models designed to process and analyse enormous datasets (e.g., Batty 2013; Bibri 2019b; Kitchin 2014a, 2016; Miller 2010) containing varied, real–time, exhaustive, fine–grained, indexical, flexible, evolvable, relational type of data. This pertains particularly to the process of knowledge discovery, which involves carefully choosing variable selection mechanisms, encoding schemes, preprocessing, reductions, and projections of the data prior to discovering the intended patterns and building the relevant models, as well as their evaluation, interpretation, and visualization. The pursuit of mastering the complexity of the process of knowledge discovery for smart sustainable/sustainable smart cities requires building an entirely new holistic system for big data analytics (see Bibri 2019c for a detailed discussion).

Furthermore, conducting scientific and academic research using advanced big data analytics techniques has positive, wide–ranging implications for urban sustainability (Table 1). This spans designs, strategies, policies, operations, functions, and services in relation to various urban domains with respect to advancing the existing forms of theoretical and practical knowledge within the domain of smart sustainable/sustainable smart urbanism.

- Overcoming the limitations of ’small data’ studies associated with such data collection and analysis methods as surveys, focus groups, case studies, participatory observations, interviews, content analyses, and ethnographies, including high cost, infrequent periodicity, quick obsolescence, inaccuracy, incompleteness, as well as subjectivity and biases.
- Overcoming the inherent deficiencies of the small samples of data that are tightly focused, time– and space–specific, restricted in scope and scale, and relatively expensive to generate and analyse, which affects the robustness of research results.
- Drastically changing the way the research data can be collected, processed, analyzed, modeled, and simulated within various academic and scientific research domains so as to make decisions easier to judge and more fact–based in relation to urban operations, functions, strategies, plans, policies, and other practices.
- Completely redefining urban problems and understanding them in new ways, as well as enabling entirely novel ways to tackle them, thereby doing more than just enhancing existing practices, especially in relation to sustainability.
- Transforming and advancing knowledge based on the deluge of urban data that seeks to provide more sophisticated, wider–scale, finer–grained, real–time understanding, and control of various aspects and complexities of urbanity.
- Enabling well–informed, knowledge–driven practices based on advanced forms of intelligence with regard to the operational functioning, management, design, planning, and development of urban systems in the context of sustainability.
- Promoting and facilitating openness and access to public data and their integration with the private information assets for use in city analytics and big data studies to advance the knowledge about sustainability.
- Advancing environmental indicators and objective targets for the purpose of monitoring progress, implementing strategies, allocating resources, and increasing the accountability of stakeholders.
- Enabling novel and harmonising urban–level metrics for monitoring the goals of sustainable development through more objective and robust indicators and targets developed and continuously enhanced based on big data analytics.
- Exploring and discovering laws and principles of sustainability pertaining to environmental and socio–economic aspects, and allowing an inference of stakeholders’ responses to operations, functions, services, strategies, designs, and policies in relevance to sustainability.

Table 1: Key benefits of big data analytics for academic and scientific research

Smart sustainable/sustainable smart cities are increasingly being permeated with big data technologies and their novel applications in terms of their systems and domains. The range of the emerging big data applications as novel analytical and practical solutions that can be utilized for sustainability is potentially huge, as many as the case situations where big data analytics can be of relevance to support and enhance some sort of decision or insight in connection with the various aspects of sustainability. For the anatomy of the data–driven smart sustainable city, including a detailed list of big data applications for multiple systems and domains a part from the above, the interested reader can be directed to Bibri (2019d).

We are living at the dawn of what has been termed ‘the fourth paradigm of science,’ a scientific revolution that is marked by both the emergence of big data science and analytics, and by the increasing adoption of the underlying technologies (large–scale computation, data–intensive techniques and algorithms, and advanced mathematical models) in scientific and scholarly research practices. Everything about science development or knowledge production is fundamentally changing thanks to the ever–increasing deluge of data. This is the primary fuel of the new age, which powerful computational processes or analytics algorithms are using to generate valuable knowledge for enhanced decision–making, and deep insights pertaining to a wide variety of practical uses and applications. The scope and impact of big data science and analytics will continue to expand enormously in the upcoming decades as scientific data and data about all branches of science become overwhelmingly abundant and ubiquitously available. Especially, significant progress has been made within data science, information science, computer science, software engineering, statistics, and complexity science with respect to handling and extracting knowledge and insights from big data and these have been utilized within urban science.

Of particular relevance, big data science and analytics is instigating a drastic change in the way both smart cities and sustainable cities are studied and understood as well as planned, designed, developed, operated, managed, and governed in the context of sustainability in the face of urbanization. This relates to what has been dubbed data–driven smart sustainable urbanism, which is underpinned by realist epistemology and instrumental rationality (Bibri 2019a, c). Realist epistemology posits that there exist an external reality which operates independently of an observer and which can be objectively and accurately measured, tracked, analysed, modeled, simulated, and visualized to reveal the world as it actually is (Kitchin 2016a). Instrumental rationality is a pursuit of any suitable means necessary to achieve a specific end. Specifically, it is practical reasoning serving for making decisions on how to efficiently perform technical tasks, solve problems, overcome challenges, and resolve conflicts by regarding the factors involved in a situation as variables to be understood and controlled. As such, it underpins the conception that cities can be operated, regulated, managed, and planned through a set of data levers and analytics, and that urban issues can be solved through a range of technical solutions thanks to the ability of probing the deluge of urban data in neutral, value–free, and objective ways to reveal a form of truth about cities. Further, epistemological realism and instrumental reality are informed by urban science, which seeks to make cities more sustainable, resilient, efficient, livable, and equitable by rendering them more knowable, controllable, and tractable.

The urban science approach is shaped by two epistemological positions. The first is a form of inductive empiricism in which the data deluge, through analytics as manifested in the data being wrangled through an array of multitudinous algorithms to discover the most salient factors concerning complex phenomena, can speak for itself free of human framing and subjectivism, and without being guided by theory (as based on conceptual foundations, prior empirical findings, and scientific literature). As argued by Anderson (2008), 'the data deluge makes the scientific method obsolete' and that within big data studies 'correlation supersedes causation, and science can advance even without coherent models, unified theories, or really any mechanistic explanation at all'. The second is data–driven science, which seeks to generate hypotheses out of the data rather than out of the theory, thereby seeking to hold to the tenets of the scientific method and knowledge–driven science (Kelling et al. 2009). Here, the conventional deductive approach can still be employed to test the validity of potential hypotheses but on the basis of guided knowledge discovery techniques that can be used to mine the data to identify such hypotheses. It is argued that data–driven science will become the new dominant mode of scientific method in the upcoming Exabyte/Zettabyte Age because its epistemology is suited to exploring and extracting useful knowledge and valuable insights from enormous, relational datasets of high potential to generate more holistic and extensive models and theories of entire complex systems rather than parts of them, an aspect which traditional knowledge–driven science has failed to achieve (Kelling et al. 2009; Miller 2010). However, both epistemological positions are evident in urban science, with a preference on the latter.

What will be exciting to witness in the near future is how data science will evolve and affect urban science and sustainability science; what new techniques will be invented that would not have come into existence if not for the amalgamation of the parental disciplines of data science, as well as the extent to which they will radically change urban sustainability science; and what new kinds of urban problems will urban sustainability science, using more advanced big data computing and the underpinning technologies, be able to solve.

On the whole, the deluge of urban data manifestly hides in itself the solutions to many challenges and problems associated with sustainability and urbanization, provides raw ingredients to build tomorrow's human engineered systems, and plays a key role in understanding urban constituents as data agents. To put it differently, as concluded by Bibri and Krogstie (2018), there is tremendous potential for transforming the knowledge of smart sustainable/sustainable smart urbanism through the creation of a data deluge whose analysis can provide much more sophisticated, finer–grained, wider–scale, real–time understanding and control of various aspects of urbanity in the upcoming Zettabyte age. In order to unlock and exploit this potential and thus understand urban phenomena in terms of the urbanization and organisation of cities, as well as to enhance and advance the practice of urban planning, design, and development, smart sustainable/sustainable smart cities are increasingly being digitally instrumented, datafied, and computerized using cutting–edge technologies with respect to big data ecosystems and related computing infrastructures.

4.4. Technological Advancements

We are currently experiencing the accelerated instrumentation, datafication, and computerization of the city in a rapidly urbanizing world and witnessing the dawn of the big data era in everyday life. Our urban everydayness is entangled with data sensing, data processing, and communication networking, and our wired world generates and analyzes overwhelming and incredible amounts of data. The modern city is turning into constellations of instruments and computers across many scales and morphing into a haze of software instructions, which are becoming essential to the operational functioning, planning, design, development, and governance of the city. In particular, the datafication of spatiotemporal citywide events has become a salient factor for the practice of smart sustainable/sustainable smart urbanism.

4.4.1. Instrumentation

The big data revolution is set to erupt in both smart cities and sustainable cities throughout the world. This is manifested in bits meeting bricks on a vast scale as instrumentation is routinely pervading the spaces we live in. Smart sustainable/sustainable smart cities are depicted as constellations of instruments for measurement and control across many spatial scales that are connected through fixed and wirelessly ad hoc and mobile networks with a modicum of intelligence, which provide and coordinate continuous data regarding different aspects of urbanity in terms of the flow of decisions about the physical, infrastructural, operational, functional, and socio–economic forms of smart sustainable/sustainable smart cities. As such, the instrumentation of such cities offers the prospect of an objectively measured, real–time analysis of urban life and infrastructure, and opens up dramatically different forms of social organisation. It is the domain of the ICT industry that is providing the detailed hardware and software to provide the operating system for smart sustainable/sustainable smart cities. This infrastructure entails integration, data collection and mining, decision making, practice enhancement, and service delivery in relation to sustainability, efficiency, resilience, equity, and the quality of life.

While there are different approaches to generating urban data (e.g., directed, indirected, volunteered, etc.), the automated one is the most common and prominent among them. It pertains to various automatic functions of the devices and systems that are widely deployed and networked across urban environments. Indeed, the automated approach to urban data generation has recently captured the imagination of those concerned with understanding, operating, managing, and planning cities, as well as seeking useful insights into urban systems, in particular in relation to the environment in the framework of the IoT. Indeed, there has been increased interest in sensor networks and the IoT and the tracking and tracing of people and objects (Kitchin 2014a). For example, sensors networks can be used to monitor the operation and condition of urban and public infrastructures, such as roads, rails, tunnels, sewage systems, water systems, power and gas provision systems, hospitals, facilities, parks, and environmental conditions. In this context, smart sustainable cities offer the prospect of real–time analysis of the processes operating and organizing urban life, which is of paramount importance to advancing the different aspects of sustainability. There are a number of tools associated mainly with sensors that can be employed in the automated approach to generating urban data (Batty et al., 2012; Bibri 2018b; Dodge and Kitchin 2007; Kitchin 2014; Kitchin and Dodge 2011), including the following:

- GPS in vehicles and on people
- Smart tickets that are used to trace passenger travel
- RFID tags attached to objects and people
- Sensed data generated by a variety of sensors and actuators embedded into the objects or environments that regularly communicate their measurements
- Capture systems in which the means of performing tasks captures data about those tasks
- Digital devices that record and communicate the history of their own use
- Digital traces left through purchase of goods and related demand supply situations
- Transactions and interactions across digital networks that not only transfer information, but also generate data about the transactions and interactions themselves
- Clickstream data that record how people navigate through websites or apps
- Automatic meter reading (AMR) that communicates utility usage on a continuous basis
- Automated monitoring of public services provision
- The scanning of machine–readable objects such as travel passes, passports, or barcodes on parcels that register payment and movement through a system
- Machine to machine interactions across the IoT
- Uniquely indexical objects and machines that conduct automatic work as part of the IoT, communicating about their use and traceability if they are mobile (automatic doors, lighting and heating systems, washing machines, security alarms, wifi router boxes, etc.)
- Transponders that monitor throughput at toll–booths, measuring vehicle flow along a road or the number of empty spaces in a car park, and track the progress of buses and trains along a route.

In the domain of urbanism, these categories of digital instrumentation provide abundant, systematic, dynamic, varied, well–defined, resolute, relatively cheap data about urban processes and activities, allowing for real–time analytics and adaptive forms of planning and management (Kloeckl, Senn and Ratti 2012). They can continually send data to an array of control and management systems, such as urban operations centers, centralized control rooms, intelligent transport systems, logistics management systems, energy grids, and building management systems that can process and respond in real time to the data flow.

Not all data are equally generated, and their variety is associated with the purpose of their use, among others. There are opportunistic data which are collected for one purpose and then used for another, e.g., data owned by cellphone companies to run their operations but used by transport companies to better understand urban mobility. User–generated data result from the engagement of citizens, e.g., data from social media platforms which provide valuable information to better understand today's cities. Purposely sensed data, e.g., automated data, reflect the power of ubiquitous urban sensors that can be deployed ad hoc in public and private spaces to better understand some aspects of urban life and dynamics.

Moreover, the various sensor recording parameters, their length as to the collected data, where they are located, what kinds of sensors are embedded in which environments, their settings and calibration, their integration and fusion, and their exhaustiveness as technical configurations and deployments determine the nature of the produced data and the way they are stored, managed, processed, analyzed, and disciplined.

In view of the above, embedding more and more advanced ICT in various forms into smart sustainable/sustainable smart cities will undoubtedly continue and even escalate for the purpose of providing the most suitable tools and techniques for handling the underlying complexity and thus dealing with the challenges they are facing and will continue to face. Especially, advanced ICT has an instrumental and shaping role in not only monitoring, understanding, and analyzing such cities, but also in improving sustainability, efficiency, resilience, and the quality of life in them.

4.4.2. Datafication

In recent years, there has been a marked intensification of datafication. This is manifested in a radical expansion in the volume, range, variety, and granularity of the data being generated about urban environments and citizens (e.g., Crawford and Schultz 2014; Kitchin 2014a, 2016; Strandberg 2014), with the aim of quantifying the whole of the city (Bibri 2019b). Datafication describes an urban trend of defining the key to core city operations and functions through a reliance on big data computing and underpinning technologies. In other words, it denotes that cities today are dependent upon their data to operate properly—and even to function at all with regard to many domains of urban life. It also refers to the collective tools, processes, and technologies used to transform a city to a data–driven enterprise. In short, datafication involves turning many aspects of urban life into computerized data and transforming this information into value. As such, this concept helps better frame the changes taking place now (Cukier and Mayer–Schoenberger 2013).

A city that implements datafication is said to be datafied. To datafy a city is to put it in a quantified format so it can be structured, harnessed, and analyzed. Cities are taking any possible quantifiable metric and squeezing useful knowledge out of it for enhanced decision–making and deep insights pertaining to many domains of urban life. Datafication entails that in a modern data–oriented urban landscape, a city's performance is contingent on having control over the storage, management, processing, and analysis of the data, as well as on the extracted knowledge in the form of applied intelligence. Tackling sustainability and urbanization issues is one of the key concerns of the datafication of the contemporary city. To put it differently, the urban world is drowning in data—and if planners and policymakers realize the potential of harnessing these data in collaboration with urban scientists and data scientists, the outcome could solve major global challenges. The point at issue is that we generate enormous amounts of data on a daily basis, a binary trail of breadcrumbs that forms a map of urban life in terms of citizens' experiences and urban dynamics, and hence the resulting disparate datasets can, if harnessed properly, open up a unique window of, and represent a goldmine, opportunity for making cities more sustainable and in tune with citizens' actual needs and aspirations.

Indeed, there has recently been much enthusiasm in the domain of smart sustainable/sustainable smart urbanism about the immense opportunities and fascinating possibilities created by the data deluge and its extensive sources with regard to optimizing and enhancing existing urban practices and processes in line with the goals of sustainable development. This results from thinking about and understanding sustainability and urbanization and their relationships in a data–analytic fashion for the purpose of generating and applying knowledge–driven, fact–based, strategic decisions (Bibri and Krogstie 2018) in relation to such urban domains as transport, traffic, mobility, energy, environment, buildings, infrastructure, healthcare, public safety, design and planning, and governance.

4.4.3. Public, Private, and Open Data Types and Issues

To provide a very rich nexus of possibilities in terms of providing new and open sources of urban data necessary for better understanding the way smart sustainable/sustainable smart cities function entails linking GPS, satellite remote–sensing and other forms of sensing, scanning technologies, and online interactive data systems focussed on crowd–sourcing, all with the automation of standard secondary sources of data. In this respect, as elucidated by Bibri (2018a, p. 220), 'in the urban domain, some data are open and thus accessible to the public for use, while other data are confidential and hence pose privacy issues. Also, some data are available virtually for free while other data require effort to obtain or even need to be acquired. Still not all the data needed for building solutions to a given urban sustainability problem exist. Hence, some data are likely to necessitate entire ancillary projects (providing necessary support to the primary activities or operation of the involved urban stakeholders) as organizations, institutions, and enterprises to arrange their collection and storage.'

Urban systems, domains, and networks constitute the main source of data deluge, which is generated by various urban entities, including governmental agencies, authorities, administrators, institutions, organizations, enterprises, communities, and individual citizens by means of urban operations, functions, services, designs, strategies, and policies. Examples of urban data include observational data, transactional data, environmental data, socio–economic data, geospatial data, temporal data, administrative records, household–level surveys, collective mobility records, transportation and travel data, citizenry participation, official statistics, social media and participatory sensing, social network surveys, and so on (Bibri 2018a). Moreover, the outcome of the data collected, stored, and organized in digital databases and hence conjoined and shared is vast troves of varied, real–time, exhaustive, fine–grained, indexical, flexible, evolvable, relational, contextual, and, more importantly, actionable data, which are routinely generated about urban environments and citizens (Bibri 2019b; Kitchin 2014a, 2015a, 2016a). This is being done by a range of public and private organizations (see Kitchin 2016a for a detailed list).

The above indicates that much of these data constitute a private asset which is closed in nature, but can still be freely shared with city governments and authorities. In some cases, these data are open in nature through data infrastructures for the purpose to be meshed with the data generated by local authorities and governmental agencies for analytical purposes and endeavors. Indeed, universities, research centers, innovation labs, urban operations centers, and governments are increasingly working together to share information and thereby becoming partners in the process of urban planning, design, and development, especially in relation to sustainability. Similarly, urban big data from heterogenous and distributed sources produce a highly granular, longitudinal, holistic understanding of urban systems and enable them to be managed in real time. Data about how urban systems are performing can be streamed back from across the data infrastructure (related to the shared data considered as private asset), analyzed together with the data generated by local authorities and state agencies, and appropriate responses returned to control and management systems.

Open data have become a key tool in redefining this process. That is why many governments are using such data to understand how sectors are affecting strategies to mitigate or overcome the challenges of sustainability. Open data usage can also promote transparency and build trust in government decision–making and official policies. In addition, one of the most significant innovations being embraced by the world's urban operations centers, research centers, and innovation labs is the movement of open data, a form of information sharing aimed at improving any aspect of urban life or urbanity. In an open–data environment, datasets from a number of urban sectors and countless other municipal sectors and state authorities are made available to optimize and enhance urban operations, functions, services, designs, strategies, and policies. For instance, when combined with data from government sources, such as information on air quality, traffic patterns, or health statistics, user–generated information can lead to building cities that are more in tune with the needs and aspirations of citizens using advanced technologies.

Within cities, citizens, activities, movements, processes, physical structures, urban infrastructure, distribution systems and networks, natural ecosystems, spatial organizations, scale stabilizations, socio–economic networks, facilities, services, spaces, and citizen objects all contribute to the generation of the colossal amounts of data from heterogeneous and distributed sources. Basically, virtually every aspect of urbanity has become open to, and instrumented for, data collection, processing, and analysis. As a result, vast troves of information have become widely available on numerous aspects of urbanity, including social trends, global shifts, environmental dynamics, socio–economic needs, spatial and scalar patterns, land use patterns, travel and mobility patterns, traffic patterns, energy consumption patterns, life quality levels, and citizens' lifestyles and participation levels. The data from these sources and on these aspects cascade into urban data deluge, which calls for prudent big data applications that can churn out useful knowledge and valuable insights from this huge deluge. The sustainability of smart cities and the smartness of sustainable cities are being digitally fueled and driven by the enormous data collected for analysis and deployment for enhanced decision–making purposes and innovative solutions development.

In that respect, the unfolding and soaring deluge of urban data is increasingly stimulating wide–scale attempts to extract value from and make sense of such data, which is driven primarily by the desire to translate actionable data and data analytics into new modes of data–driven operational functioning, management, planning, and governance focused more and more on advancing smart sustainable/sustainable smart urbanism. In more detail, the value of the useful knowledge extracted from the deluge of urban data lies in improving physical forms, infrastructures, resources, networks, facilities, and services by developing urban intelligence functions for automating and supporting decisions pertaining to control, automation, optimization, management, and prediction.

There are many examples of cities that show ways in which vast quantities of data can improve sustainability, efficiency, resilience, equity, and the quality of urban life. They suggest the range of opportunities that could open up when planners, scholars, urban scientists, and citizens use their imagination to leverage the Fourth Paradigm of Scientific Revolution's capacity to produce information and discover new knowledge. To scale up the opportunities these examples of cities demonstrate, it is crucial that an increasing number of people have access to data and participate in a collective discussion on their use, potential, and benefits in terms of sustainability. Big data should become, as much as possible, open data to have a profound impact on smart sustainable/sustainable smart cities. However, a world of truly open data will take time to build. But governments have already recognized the importance of open data in solving key sustainability challenges. There are many ways of how improved access to data can streamline sustainable urban planning and design.

However, it is critically important to develop and implement guidelines and principles to facilitate the integration of all the different cross–thematic data categories into coherent databases prior to any kind of analytics (e.g., data mining, statistical analysis, predictive modeling, regression analysis, etc.). The underlying assumption is that urban big data are generated from widely different and at times unstructured sources, each with particular format and related technical and methodological challenges. In this regard, research within smart sustainable/sustainable smart urbanism should focus on addressing several issues related to the public policy domain of urban big data, including the following:

- How to collect, store, and coalesce various types of large data in city data warehouse
- Which urban entities (or stakeholders) should be involved within different urban domains
- What concerns are of relevance for the diffusion of big data technologies and platforms
- The interoperability between various data standards (open, proprietary, etc.)
- How urban citizens should be involved in the decision–making process pertaining to the selection and deployment of urban big data innovations
- The ethical and legal dimensions in terms of data access and control and thus privacy and security.

In fact, policy and politics are at the core of smart sustainable/sustainable smart cities, including the uses of big data in terms of development, implementation, functioning, and governance as related to urban planning and development in this context.

4.5. Socio–Political Influences from Different Philosophical Perspectives

4.5.1. Smart Sustainable Cities as a Socially Constructed Phenomenon

The relationship between planning, design, and development interventions, the goals of sustainable development (Bulkeley and Betsill 2005; Williams 2009), and big data technologies is a subject of much debate (Bibri 2018a, 2019b, c; Bibri and Krogstie 2016; Kitchin 2014a, 2015a, 2016a). This means that realizing smart sustainable/sustainable smart cities requires making countless decisions about urban form and structures, infrastructure development, and governance, as well as the extent to which big data analytics can facilitate and enhance decision–making processes. This occurs through social processes consisting of complex negotiations and sometimes even conflicts. Following this perspective, smart sustainable/sustainable smart cities are socially constructed through policy–making processes and thus planning practices, design strategies, and development projects. As such, they are the outcome of social processes involving numerous stakeholders. Social constructionism deals with the development of jointly constructed understandings of the world that form the basis for shared assumptions about reality. This occurs through discourses and discursive formations. Foucault (1972) defines discourse as a group of statements which provide a language for talking about a way of representing the knowledge about a particular topic at a particular historical moment. Hajer (1995, p. 44) defines discourse as 'a specific ensemble of ideas, concepts, and categorizations that are produced, reproduced, and transformed in a particular set of practices and through which meaning is given to physical and social realities'. In the context of this paper, underlying the term 'discourse' is the idea that language as a form of discursive practice is structured according to a system of statements (e.g., what can be said about smart sustainable/sustainable smart cities) used by people (e.g., policymakers, planners, developers, researchers, scholars, scientists, etc.) as a particular way of understanding and talking about the urban world (e.g., smart sustainable urban planning and development and related environmental, economic, and social benefits), as well as taking part in different domains of urban life (e.g., urban planning, urban development, urban research, urban science, urban informatics, urban analytics, etc.). Further, in relation to the manner by which discourses are applied to the social world, 'discursive formations' in a given society comprise institutional apparatuses and their techniques, such as the institutions, the systems of thought, the rules, the things, and the subjects (Foucault 1980), As a structure, institutions constitute 'background ideational abilities' contributing with the rationality of a specific setting internalized by the agents (Schmidt 2008, p. 315). As a construct, they consist of 'foreground ideational abilities' which, as governed by communicative logic, enable institutional change as the deliberative nature of discourse allows agents to 'conceive of and talk about institutions as objects at a distance, and to dissociate themselves from them even as they continue to use them' (Schmidt 2008, p. 316). However, social reality is produced and made real, i.e., socially anchored and institutionalized actions become meaningful through discourse, and social interactions with their various forms of social processes cannot be utterly understood without reference to the discourses that give them meaning in the first place (Bibri and Krpgstie 2016). In short, the constitution of social life occurs through discursive practices: the production, interpretation, and consumption of text: scientific reports, academic publications, policy reports, planning documents, development strategies, and so on (e.g., related to data–driven smart sustainable/ sustainable smart urbanism). A discursive practice refers to the process through which (dominant) reality comes into being (Foucault 1972). It in turn represents actions that are taken as part of the real–world application of different discourses of knowledge. It also entails activities that people engage in, deliberately, with the aim of developing knowledge and skills (Bibri 2019).

The dialectic of discursivity and materiality is crucial to the social construction of the phenomenon of smart sustainable/ sustainable smart cities, i.e., developing, institutionalizing, and conventionalizing it through social constructs, which are produced by, and depend on, contingent aspects of social selves through social practices. Constituting urban objects and their related subjects with specific material and ideal interests (discursive constructions), the discourse of smart sustainable/smart sustainable cities plays a role alongside material mechanisms and practices in transforming urban domination (Bibri and Krogstie 2006). This discourse is reproduced materially through institutional and organizational apparatuses and their techniques, actors, and practices. This material reproduction entails the translation of the underlying urban visions into hegemonic urban strategies and initiatives, as well as their institutionalization in urban structures and practices. As constructed in the light of new conceptions about the scientific, technological, environmental, economic, social, and cultural changes over the past decade—smart sustainable/sustainable smart cities contain 'an all–embracing understanding of the problems cities are facing and is also the defining context for suggested solutions' (Jessop 1998, p. 78) as future possibilities for the problems and challenges of sustainability and urbanization. In sum, structuring and institutionalizing signify a dominant discourse, which influences not only how we understand a specific problem, but also how we act upon it, including, as added by (Schmidt 2008), the interactive processes by which ideas are conveyed.

4.5.2. The Relationship Between Societal Structures and Urban Structures: The Shaping Influence of Political Action

Smart sustainable/sustainable smart cities are the product of socio–culturally–conditioned frameworks, including how and why the underlying data–driven urbanism practices have emerged and become disseminated at the urban level and hence materially produced through diverse socio–political institutions and organizations. Therefore, it is important to recognize the interplay between smart sustainable/sustainable smart cities as a form of sustainability transition and other societal scales, as well as the links to political processes on a macro level, i.e., regulatory policies and governance arrangements. This relates to the dialectic relationship between societal structures and urban structures in that the former affect and are affected by the latter. The focus here is on how the former affect the latter. This one way relationship has been approached from a variety of perspectives, including transition governance, innovation system, and discourse analysis. From a transition governance perspective, government is one of the key actors involved in any form of sustainability transition through various governance arrangements, including funding schemes, research management (regulation of public research institutes), innovation and technology policies, regulatory standards, market manipulations, public–private collaborations and partnerships, and so on (Bibri 2015, 2019b). In this respect, the government generates top–down pressure from regulation and policy and the use of market and other forms of incentives, while promoting, spurring, and stimulating the collective learning mechanisms by supporting innovation financially and providing access to the needed knowledge (Rotmans, Kemp and van Asselt 2001). Further, recommendations for smart sustainable/sustainable smart cities as a major urban transformation and a leading paradigm of urbanism, which entails a set of intertwined socio–technical systems and a cluster of interrelated discourses embedded in the wider socio–technical landscape, are unlikely to proceed without parallel political action. Drastic shifts to sustainable (and) technological regimes 'entail concomitantly radical changes to the socio–technical landscape of politics, institutions, the economy, and social values' (Smith 2003, p. 131).

Furthermore, political action is of influence in the context of smart sustainable/sustainable smart cities as both an academic discourse and an amalgam of innovation systems (Bibri and Krogstie 2016). Indeed, it is at the core of discourse theory (e.g., Foucault 1972) in terms of the material mechanisms and practices that can be used to translate any urban vision into concrete projects and strategies and their institutionalization in urban structures and practices. Similarly, political action is at the heart of the theoretical models of innovation system. In this regard, political processes represent the set–up under which dynamic networks of urban actors can interact within diverse industrial sectors in the development, diffusion, and utilization of knowledge and technology pertaining to big data technology in the context of smart sustainable/sustainable smart urbanism.

On the whole, political action is of critical importance to, if not determining in, the emergence, materialisation, expansion, functioning, and evolution of data–driven smart sustainable/sustainable smart urbanism as an intellectual discourse. The main argument is that this approach to sustainable urban development—is not an element closed in the 'ivory tower' of the research and industry communities, but it is influenced by the macro–political practices in connection with sustainable development. Among the common political mechanisms used in this process, which represent facets of the operations that link industrial ecology and political action, include the following (Bibri 2019b):

- Creating regulatory and policy instrument and incentives and carrying out legislations.
- Assigning scholarly roles and institutional positions to particular institutions and organisations, thereby authorising them and legitimising their actions as to R&D activities, technology and innovation policy formation, constructing and implementing new visions, and so on.
- Government involvement in projects and initiatives through funnelling investments, providing positive incentives, advocating product and service adoption, organising forums and symposiums, encouraging national and local programs, and devising comprehensive plans.

4.5.3. The Relationship Between Science, Technology, and Society (STS)

The role of science–based technology in societal development is a subject area which is positioned within the research and academic field of STS. This is concerned with the ways in which new technology emerges from different perspectives, why it becomes institutionalized and interwoven with politics and policy—cultural dissemination, as well as the potential risks it poses to sustainability. However, S&T in this context is associated with big data computing and its technological applications and the increasing role this form of ICT of pervasive computing plays in advancing sustainability within contemporary cities. This rapidly evolving form of S&T and related role in smart sustainable/ sustainable smart cities has recently permeated urban and academic debates as well as politics and policy across the globe, and is accordingly seen as key for solving the environmental and socio–economic challenges pertaining to sustainability and urbanization facing modern and future cities. Big data computing and its technological applications is drastically changing long–standing forms of city structures, systems, and processes, and revolutionising urban transformation models. Major urban transformations are promised as a result of upcoming and future advancements and innovations in big data analytics and its application. The existing evidence (e.g., Batty et al. 2012; Al Nuaimi et al. 2015; Angelidou et al. 2017; Bibri 2018b, 2019a, b, c, d; Bettencourt 2014) already lends itself to the argument that the use of big data technology and its novel applications across various urban domains makes this technology a salient factor for advancing sustainability. If its research, development, and innovation continue further to be linked with the agenda of sustainable development and the goals of sustainability, i.e., to be utilized meaningfully and strategically, big data computing will have positive, profound, and long–term impacts on smart sustainable/sustainable smart cities of the future. It is projected to yield hitherto unrealized environmental gains and socio–economic benefits, owing to its technological superiority in terms of the novel applications and services that provide high performance and concrete value. All in all, big data technology as an instance of science–based technology is socio–culturally constructed to have a determinant role in instigating major social changes on multiple scales due to its transformational power which resides or is embodied in its disruptive, synergistic, and substantive effects. In relation to this, the coalescence of computing, data processing, and communication networks is unleashing a wealth of opportunities and proving a powerful driver for innovation and change, as well as blurring the boundaries between domains within different societal spheres. Big data technology does not just enable us to *do* new things; it *shapes* how we do them. It is important not to underplay the radical social transformations that are likely to result from the implementation of this advanced technology.

In the meantime, advanced ICT as a set of applications of scientific discoveries in computing has been evolving just as the underlying social knowledge about how to understand it and the way in which it can be applied to enhance urbanism as a social practice have been evolving. This is predicated on the assumption that science–based technologies develop dependently of society (of which cities represent a microcosm or an example) in a reciprocal shaping process where they both are shaped at the same time and thus affect one another and evolve (Bibri and Krogstie 2016). In line with this argument, Batty et al. 2012, p. 506) state, 'the crucible for technological innovation is the cultural context in which it takes place. Technology is a social construction as much as it is a material or ethereal one, and its application is intrinsically social. There is an increasing consensus that cities represent the crucible for technological innovations and that larger cities with a highly educated workforce represent the best places where progress can be made with their invention and application… ICT holds the key to a better society and it will be most clearly demonstrated in large cities.' Science and technology shape and influence, and are shaped and influenced by, cities as social organizations. Accordingly, big data computing and the underpinning technologies in the form of scientific and applied knowledge are embedded in and thus shaped and influenced by the urban context as part of the wider socio–cultural system within which they arise, and which they in turn shape and influence. By the same token, the urban conditions as social structures and practices shape scientific knowledge and activity in terms of data science and urban science, which in turn shape urbanism as part of such conditions. On this note, Bibri and Krogstie (2016) conclude that smart sustainable/ sustainable smart cities and what they entail in terms of planning, design, and development as being responsive to a form of data−driven urbanism 'are mediated by and situated within ecologically and technologically advanced societies. As urban manifestations of scientific knowledge and technological innovation, they are shaped by, and also shape, socio–cultural and politico–institutional structures,' specifically those pertaining to the urban sphere of society.

Following social constructionism, the ways we understand, view, and explain the world are subject to constant reconfigurations, perennially changing, as they are historically contingent and socio–culturally specific; and our knowledge of the world is not pure representations of nature and thus should not be treated as absolute or objective truths (e.g., Burr 1995; Gergen 1985). In other words, social constructionist worldview posits that we are fundamentally cultural and historical beings and our knowledge about the world is the product of people's daily making of history, i.e., historically situated interchanges among them (Gergen 1985). One implication of this is that scientific discoveries and technological developments will continuously be situated in a volatile and tense relationship with an inherently contingent, heterogeneous, fractured, conflictual, plural, reflexive social world (Bibri 2015). This has direct implications for how smart sustainable/sustainable smart cities will evolve and other paradigms of urbanism will emerge and dominate again.

To elaborate further, Foucault (1972) asserts that knowledge, whether theoretical or silently invested in practice, is fundamentally culturally contextual and historically situated, as well as a matter of episteme, the rigid understandings of truth that lies beneath all the discourses of knowledge of a particular epoch, which is a subset of historical *a priori/* positive unconscious of knowledge. This implies that different periods of history constitute different epistemological fields or systems of thoughts, and all social constructions of (scientific) knowledge fall under the episteme of a historical epoch, to reiterate. Likewise, Kuhn (1962) challenges the then prevalent view of science as a buildup of objective facts towards a more understanding of truth, contending that scientific discoveries are contingent upon the kinds of questions scientists ask, which in turn hinge on their philosophical commitments, among others. One corollary of this is that the prevailing scientific foundations, assumptions, and methods used to probe or look at the world become riddled with issues, which can incite radical scientific revolutions. These are dubbed by Kuhn as paradigm shifts, which alter the behavioral patterns underlying the evolution of knowledge by changing how scientists view the world in terms of the way they go about to reason about nature or reality, i.e., the questions they formulate about the world as well as the methods they employ to understand it. For a detailed discussion of the epistemic and paradigmatic shifts the sciences underlying smart sustainable/sustainable smart urbanism are undergoing in light of big data science and analytics, the interested reader can be directed to Bibri (2019c).

5. Urban Science and Big Data Technology as Social Constructions: Inherent Flaws, Limits, and Biases

Epistemological realism is a subcategory of objectivism that holds that what is known about an object exists independently of human mind. In this context, it underpins the computational inner workings of data-driven smart sustainable/sustainable smart urbanism. As such, it sustain and is informed by urban science (a field in which data science and analytics is practiced). This seeks to make cities more measurable, knowable, and controllable in terms of their operational functioning, management, planning, and development, and thereby more sustainable, resilient, efficient, and equitable (Bibri 2019b, c). These practices are indeed becoming highly responsive to a form of data-driven urbanism that is the key mode of production for smart sustainable/sustainable smart cities, whose monitoring, understanding, and analysis are accordingly increasingly relying on the core enabling technologies of big data analytics. However, several scientific and computational approaches to cities, such as digital mapping and geographic information systems, quantitative geography and urban modeling, and urban cybernetics theory and practice, as well as knowledge discovery/data mining as an advanced form of decision support, are based on a form of epistemological realism. This approach postulates 'the existence of an external reality which operates independently of an observer and which can be objectively and accurately measured, tracked, statistically analysed, modeled and visualized to reveal the world as it actually is. In other words, urban data can be unproblematically abstracted from the world in neutral, value–free and objective ways and are understood to be essential in nature; that is, fully representative of that which is being measured (they faithfully capture its essence and are independent of the measuring process)… And these data when analyzed in similarly objective ways reveal the truth about and a 'God's eye' view of cities. As such, they promote an instrumental rationality that underpins the notion that cities can be steered and managed through a set of data levers and analytics and that urban issues can be solved through a range of technical solutions' (Kitchin 2016a, p. 4). One of the implications of such a framing as to the criticism of urban science is that the scientific and computational approaches wilfully ignore the role of politics, social norms, social structures, ideology, and culture, as well as the metaphysical aspects of human life, in shaping urban relations, governance, planning, and development (Harvey 1973/2009). Another implication of such a framing associated with urban science being roundly criticized within the social sciences is that it is too atomizing, reductionist, mechanistic, essentialist, deterministic, parochial, and closely aligned with positivist thinking, collapsing diverse complex, multidimensional social structures and relationships to abstract data points and universal formulae and laws (Buttimer 1976). In addition, it produces the kind of policy interventions that both did much damage to city operations as well as failed to live up to their promises (Flood 2011).

Computational and scientific approaches to cities have been perceived as inadequate to solve urban problems due to their wicked nature. It is argued that such problems are often best solved through political/social solutions, citizen participation, and deliberative democracy, rather than technocratic forms of governance (Greenfield 2013; Kitchin, Lauriault and McArdle 2015). Moreover, such approaches are claimed to produce a limited and limiting understanding of how cities work and how they should be managed. The former pertains to foreclosing what kinds of questions can be asked and how they can be answered (Kitchin 2016a), and the latter is associated with foreclosing other forms of urban knowledge, such as knowledge derived from practice and deliberation and based on experience (Parsons 2004). In addition, computational and scientific approaches have been criticized for failing to recognize that cities are complex, intricate, multifaceted, and unpredictable systems, full of contestations and intractabilities that are not easily captured or steered, a view which undoubtedly still holds (Bibri 2019b; Bibri and Krogstie 2016; Kitchin 2016a; Kitchin, Lauriault and McArdle 2015). However, advocates of computational social and urban science counter that, in the age of big data the variety, exhaustivity, resolution, flexibility, evolvability, and relationality of data, coupled with the growing power of big data computation and analytics, address some of the raised critiques, especially those related to reductionism and universalism (Kitchin 2014b). This can occur through providing more finely grained, sensitive, and nuanced analysis that can take account of context and contingency (Bibri 2019c). Nonetheless, how smart sustainable/sustainable smart cities are conceived needs a re–orientation. 'Rather than being cast as bounded, knowable, and manageable systems that can be steered and controlled in mechanical, linear ways, cities [in general] need to be framed as fluid, open, complex, multi–level, contingent and relational systems that are full of culture, politics, competing interests and wicked problems and often unfold in unpredictable ways… [C]ity analytics and its instrumental rationality should not be allowed to simply trump reason and experience, or other sources of information and insight such as those based on 'small data' studies, in shaping and driving urban governance. Instead, they should be used contextually and in conjunction with each other.' (Kitchin 2016a, p. 11)

From another critical perspective, in examining the practices of urban science, paying particular attention to instrumental rationality and realist epistemology, Kitchin (2016a) concludes that urban science needs to be re–cast in this way: a reconfiguring of the underlying epistemology to openly recognize the contingent and relational nature of urban systems as well as urban processes and science. This relates to the social shaping of science–based technology and the social construction of scientific knowledge as analytical and philosophical approaches (see Bibri and Krogstie 2016 for a detailed discussion). In light of this, the re–casting in question involves recognizing that the realist assumptions, which posit that urban science can reveal fundamental truths about the city, are flawed. Urban science can only produce a particular view through a specific lens, and cannot provide neutral, objective, God's eye views of the city (Kitchin 2016a). On the one hand, the data used do not exist independently of the ideas, instruments, systems, practices, and knowledge employed—and embedded within a multidimensional context (e.g., local, national, social, political, cultural, organizational, regulatory, etc.)—to generate and process them (Ribes and Jackson 2013). To put it differently, data are never raw, but always already cooked to a particular recipe for a particular purpose (Bowker 2005; Gitelman 2013). On the other hand, big data computing and the underpinning technologies are socio–technical in nature. As such, they are not neutral, purely technical means of assembling and making sense of data; instead, they are shaped by philosophical ideas, socio–political frameworks, and ideological means (Bibri 2019b; Kitchin 2016a). In particular, big data technology is 'cultural' since it can be conceptualized as a discourse prioritizing specific concepts, ideas, claims, assumptions, and visions about the nature and practice of science and technology in society and the role of diverse actors in shaping them. There is potential for realizing that the big data–driven technologized nature of the city is neither apolitical nor inevitable. Furthermore, when engaging in a discursive–material analysis, the politics of this science–based technology doesn't become the result of the unconditioned agency of the involved actors, e.g., scholars, scientists, experts, engineers, and technologists. Rather, such technology can be conceived as specific techno–socio–political practice which depends on the agency of various actors promoting it and forming coalitions on particular technological innovations and on the political regulation of science and technology in society. All in all, big data technology is the outcome of social processes involving diverse intertwined factors and many stakeholders with a vested interest. Accordingly, urban science as a field in which data science and big data computing are practiced needs to recognize that it does not reflect the world as it actually is and to openly acknowledge its contingencies, limitations, and inherent politics, but rather actively frames and produces the world (Kitchin 2016a; Kitchin, Lauriault and McArdle 2015). This is, though, not to say: 'the fundamental approach of analytics, modeling, and simulation is radically altered, but rather that how these approaches work in messy practice is detailed and grand claims as to their veracity or validity is tempered. This would include detailing how ethical issues were considered and the research design altered appropriately.' (Kitchin 2016a, p. 11)

The main argument is that the way the technical systems are designed, operated, and steered is influenced by what Foucault (1977, p.194) calls a 'dispositif' and defines it as 'a thoroughly heterogeneous ensemble consisting of discourses, institutions, architectural forms, regulatory decisions, laws, administrative measures, scientific statements, philosophical and moral propositions.' To put it differently, a data assemblage possesses, in Kitchin's (2015a) terminology, systems of thought, the regulatory environment, organisational priorities and internal politics, institutional collaborations, funding and resourcing, technical know–how, and marketplace demand. These institutional apparatuses and their techniques relate to what Foucault (1972) terms 'power/knowledge,' that is, knowledge produced by a system of procedures to fulfil a strategic function or to achieve a particular purpose. In other words, urban big data are situated, context–dependent, contingent, framed, and selective for the purpose to achieve certain goals or ends, i.e., to monitor, empower, dictate, discipline, regulate, control, steer, centralize, produce profit, and so forth. In this context, it is legitimate to scrutinize and challenge the inner–working of technical systems and the data they produce: the mechanisms that function internally to such systems and data generation and are not outwardly visible as to the underlying politics. Or, it is necessary to critically unpack the data assemblage associated with urban big data when being under examination so as to document how this assemblage is formed and functions in practice to help generate urban processes and formations (Kitchin 2015a) for the benefit of sustainability and citizens. Such assemblage includes the core enabling technologies underlying big data computing in the context of data–driven urbanism, including sensor networks, data processing platforms, cloud or fog computing infrastructures, data warehouses, and so on. For example, where sensors are located, what kinds of sensors are embedded in which environments, their settings and calibration, their integration and fusion, and their exhaustiveness pertain to technical configurations and deployments that determine the nature of the produced data and the way they are stored, managed, processed, analyzed and disciplined. On the whole, knowledge is the products of complex socio–technical constellations that is framed and shaped by a range of technical, economic, social, cultural, and political forces, and is designed to serve particular purposes. This also applies to data in terms of producing particular outcomes, as illustrated in Table 2.

Data assemblage	
System/process performs a task	*Context frames the system/task*
• Reception/Operation (user/usage)	• Systems of thought
• Interface	• Forms of Knowledge
• Code/algorithms (software)	• Finance
• Data(base)	• Political economies
• Code Platform (operating system)	• Governmentalities & legalities
• Material Platform (infrastructure – hardware)	• Organisations and Institutions
	• Subjectivities and communities
	• Marketplace

Table 2: Data assemblage
Source: Kitchin (2015a)

6. Conclusion and Discussion

Underlying data–driven smart sustainable/sustainable smart urbanism as an instance of societal transformation is the perceived significant contribution that big data science and analytics and the underpinning technologies as an area of S&T can make to sustainable cities and smart cities in terms of improving, advancing, and maintaining their contribution to the goals of sustainable development. This is positioned within the broader debate over the role of science–based technology in societal development. As advances in computing and ICT, big data computing s and its technological applications has brought new visions on how cities as a microcosm of societies will evolve and the kind of opportunities that will be created and explored in the context of sustainability.

This paper introduced and described the key theoretical and disciplinary foundations, with an emphasis on the cross–disciplinary issues underlying the multidisciplinary topic of this study. This is meant to facilitate collaboration among different disciplines for the primary purpose of providing the theoretical underpinning and interactional knowledge that are necessary for a more integrated and broader understanding of the phenomenon of data–driven smart sustainable/ sustainable smart urbanism.

The principle aim of this paper was to examine the intertwined societal factors underlying data–driven smart sustainable/sustainable smart urbanism in terms of its materialization, success, expansion, and evolution. This examination involved various dimensions, namely shifts, trends, expected developments, and technological advancements, as well as how and why smart sustainable/sustainable smart cities as a leading paradigm of urbanism has become institutionalized and interwoven with politics and policy—urban dissemination. Accordingly, the key societal factors identified include global, technological, scholarly, scientific, and socio–political. This provides a multi–perspectival, yet unified, approach into understanding the complex phenomenon and blossoming field of data–driven smart sustainable/sustainable smart urbanism. One of the implications of the identified shifts, tends, expected developments, and technological advancements is its success, expansion, and evolution, which is projected to be fuelled by new innovations in urban science, data science, data analytics, and the underpinning technologies, along with the transformation of sustainability knowledge. On the whole, big data science and analytics is dramatically changing the rules and procedures by which sustainable cities and smart cities function in relation to sustainability, as well as paving the way for their amalgamation as approaches to urbanism.

Furthermore, this paper critically discussed urban science and big data technology as social constructions in terms of their inherent flaws, limits, and biases. In contrast to what some urban scientists and data scientists argue—that the way the city is planned, designed, and managed is less open to political influence or not politically inflicted, but rather is driven by objective, neutral views in a technocratic, pragmatic way—all technical systems and the data they produce are far from being based on value–free facts and politically benign. Therefore, urban science and big data technology do have immanent shortcomings by being socio–politically influenced. They measure values and communicate them as well as process, analyze, interpret, and display the data with limits and biases, despite the claim of applying scientific principles (framed) and generating information that reflect the truth about cities. Additionally, the more integrated and holistic view of the city provided by the data deluge remains partial and subject to caution due to the technical issues pertaining to data coverage, access, quality, and veracity, but to name a few.

The biases and limits of scientific knowledge are a case for cultural relativism. Foucault (1972) posits that it is not possible to gain access to universal truth, as there is no escape from social representations and historical contingencies, and that truth effects are created within the discourse of knowledge itself. However, a common argument (e.g., Keith 1977; Dawkins 2007, 2016) against cultural relativism suggests that it inherently contradicts, refutes, or stultifies itself. That is to say, the statement 'all is relative' is categorized either as an absolute statement or a relative one. If it is absolute, then this statement provides an example of an absolute statement, proving that not all truths are relative. If it is relative, on the other hand, then this statement does not rule out absolutes. Philosopher Hilary Putnam in (Baghramian 2004) states that some forms of relativism make it impossible to believe one is in error. If there is no truth beyond an individual's belief that something is true, then an individual cannot hold their own beliefs to be false or mistaken. Moreover, the agreement of the knowledge with its object (Heidegger 1962) as a traditional conception of truth in which explanations about how the world works can be sought varies in different sciences. The truth in physics is absolute and universal. Social relations and behaviors may not produce true regularities but stable ones. In sociology, the truth is not absolute. The laws cannot be fully rejected or fully accepted. The laws of social life differ in different places and periods. They depend on a particular cultural context and historical situation (e.g., Foucault 1972; Popper 1986). The idea of social laws relates to social physics, a field of science which uses mathematical tools inspired by physics to understand human behavior and social relations. Also known as the science of social phenomena, it is subject to invariable natural laws— compare social dynamics: social statics, as well as involves the quantitative study of human society: social statistics. It revolves around the idea of studying political and social phenomena as if they were natural forces. Recently, social physics has become a new way of understanding human behavior and social phenomena based on big data analytics (e.g., Bibri 2019b). Current urban science draws on positivistic ideas emanating within social physics which seeks to identify the social determinants and 'laws' of cities using big data computing (e.g., Kitchin 2016a).

Notwithstanding the foregoing, data–driven smart sustainable/sustainable smart urbanism is influenced by the effects of the power induced by the underlying scientific knowledge: data science, urban science, computer science, information science, engineering science, and so on. These scientific disciplines have legitimization capacity due to their association with the scientific discourse, one of today's main sources of legitimacy and authority in knowledge production, decision–making, and policy–making. In particular, the success and expansion of data–driven smart sustainable/ sustainable smart urbanism is associated with the exercise of power for the view of having a scientific function in the transformation of cities by instrumenting, datafying, and computerizing them on a massive scale (Bibri 2019b). In a nutshell, the sheer scientificity and objectivity of urban science and big data science and analytics are behind the ongoing success and expansion of such urbanism. And they are used as all–embracing solutions to persuade the majority of the city that all urban problems can be contained and solved by what they can offer as innovative solutions and sophisticated approaches. They are also used as rhetorical elements in the decision–making process, utilized as a symbolic element: the process of deploying the core enabling technologies of big data science and analytics gives a ritualistic assurance that decision–makers hold appropriate attitudes towards decision–making pertaining to smart sustainable/sustainable smart urbanism and its policy. On the whole, given the scientific discourse and related legitimation capacity underlying data–driven smart sustainable/sustainable smart urbanism as a discourse, one can subsume a range of socio–political effects under the kind of discursive mechanisms through which this discourse operates. Such mechanisms show the power of this discourse and empower the agents that promote it.

Lastly, this paper provides a form of grounding for further discussion to debate over the disruptive, synergetic, and transformational effects of big data science and analytics and the underpinning technologies on forms of urban planning, design, development, and governance in the context of smart sustainable/sustainable smart cities. Also, it presents a basis for stimulating more in–depth research in the form of both qualitative analyses and quantitative investigations focused on establishing, uncovering, substantiating, and/or challenging the assumptions underlying the relevance of big data technologies and their applications as to advancing sustainability.

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